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5aEA5. Hysteresis effects in the impinging jet noise

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Experimental acoustic investigation of under-expanded free and impinging jet is carried out for various nozzle-plate spacing. The reservoir pressure is slowly increased from atmospheric pressure to 6 bar and than decreased from 6 bar to atmospheric pressure. The free jet acoustic radiation remains same for both paths but it is observed that for impinging jet the acoustic radiations differ in some regions. The hysteresis effect observed in acoustic characteristics may be due to the presence of hysteresis effects in the recirculation zone of the impinging jet. This variation is significant for nozzle-plate spacing of 2 to 4 times jet diameter. It is also seen that the acoustic staging occurs for low pressure and high pressure for small and large nozzle-plate spacing, respectively. Keywords- Impinging jet, OASPL, NPR, Impinging tone, impinging bubble

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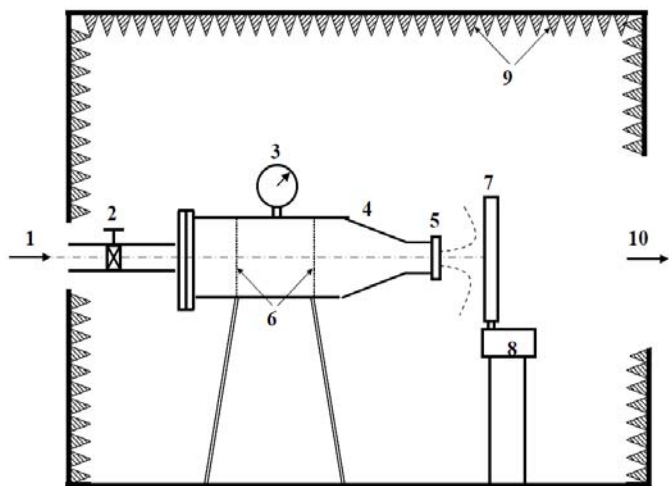
INTRODUCTION

The under expanded jet impinging on rigid surface can be found in various engineering applications such as rocket launching, vertical/short take off and landing aircraft, shock impingement heating, laser cutting in manufacturing and spray painting. Impinging jet contains both subsonic and supersonic pockets, complicated interacting shocks and expansion systems, which makes the flow structure clumsy. Several investigations have been carried out to confirm the generation of impingement tone by feedback mechanism (Neuwerth, 1974; Powell, 1988; Tam and Ahuja, 1990; Henderson and Powell, 1993). The reflected acoustic waves from the ground upon reaching the nozzle exit excite the initial shear layer and induce instability. The instability waves grow as they propagate downstream and manifest themselves as large structures. These structures in turn generate pressure fluctuations and intensify the acoustic waves further. More information about the feedback mechanism can be found in Ho and Noisseir (1981), Powell (1988), Tam and Ahuja (1990), Henderson and Powell (1993) and Krothapalli et al. (1999).

Limited information is available on various aspects of impinging jet noise, for instance, take off and landing conditions. Such problems motivated the authors to carry out a study on hysteresis effects on impinging jets. In the present study, experiments are carried out to provide some understanding of the role of impinging bubble in noise generation.

EXPERIMENTAL SETUP AND PROCEDURES

Experiments are carried out in a semi-anechoic room of size 2.5m x 2m x 2m (wedge tip-to tip) as shown in Figure 1. Polyurethane square pyramidal wedges of 6 and 3 inches are fixed to all inner surfaces except the floor. The chamber floor lined with carpet. The chamber is anechoic for frequency above 630 Hz.



1 Air inlet 2 Pressure regulator 3 Pressure Gauge 4 Settling Chamber 5 Disk holder
6 Wire meshes 7 Solid plate 8 Linear traverse 9 Anechoic Wedges 10 Air outlet

FIGURE 1. Semi-anechoic chamber with impinging jet facility

The cold free-jet test facility consists of settling chamber fixed inside anechoic room. The settling chamber has the dimensions of internal diameter of 380 mm and the length of around 700 mm connected to pressure regulating valve by pipe at one end and convergent opening at another end to fix orifice or nozzle. The settling chamber is converged from 380 mm to 43.5 mm in 100 mm distance where the required orifices are mounted using a disk holder. Initial disturbances such as turbulence and structure borne acoustic perturbations are mitigated by fixing progressive meshes and coating inner wall with foam respectively.

The air is compressed using a reciprocating air compressor and stored in the two reservoir of total capacity of 20 m^3. The compressor compresses the air up to 7.5 bar gauge. 4-inch pipe is used to supply the compressed air from the reservoir to the settling chamber.

In front of jet facility linear traverse is fixed on which the plate of required size can be mounted. The traverse can be used for varying the nozzle-plate spacing. To lessen the internal acoustic reflections from metallic surfaces are layered with acoustic foam.

A quarter inch Bruel and Kjaer microphone is used for the entire acoustic measurement. Signals are acquired by filtering at 70 KHz using low pass analog filter (Krohn-Hite Model No. 3364), and sampling at the rate of 150000 samples/sec. A piezo-resistive pressure transducer (Endevco model no. 8510C-100) mounted inside the settling chamber is used to measure settling chamber pressure. Data acquired during the experiments, is taken to frequency domain using a Matlab based FFT algorithm and overall sound pressure level (OASPL) and sound pressure level (SPL) is analyzed.

Uncertainty Analysis

The microphones are calibrated using the piston-phone calibrator of frequency 250 Hz and 124 dB power. The piezo-resistive transducer used in blow up and blow down test to obtain the stagnation pressure data has an uncertainty of ±0.2 % of full scale. The anechoic room temperature is almost constant with a maximum temperature variation of $\pm 1^{o}$ C for each trial of experiment. The sound pressure level reported here is relative to the reference pressure of 20 μPa. The error in microphone positioning is ±1 mm. The frequency resolution based on the FFT size is 37 Hz over the range of frequency from 630 Hz to 70 KHz. The noise level was repeatable within ±1 dB. The error in nozzle-plate spacing is ±1 mm.

BLOWUP AND BLOW DOWN STUDY

Blowup and blow down tests are executed to reveal the noise variation with respect pressure ratio/Mach number and also helps to find hysteresis effect if present. For these tests, orifice of 10 mm diameter is used and microphones are placed at a distance of 20d from the centre of the jet exit at an emission angle of 90^{0} and 135^{0}. The pressure regulating valve is fully opened and the compressor is started so that pressure is built in the reservoir as inflow is larger than outflow. When the reservoir pressure is crosses 6 bar, the compressor is stopped. The stagnation pressure and acoustic pressure are obtained continuously using Endevco piezo-resistive pressure transducer and B&K microphones respectively. The data collected in between starting and stopping the compressor is called blow up study and the data collected after stopping the compressor still complete draining of reservoir through the orifice is called blow down study. The acoustic measurements are carried out for the pressure ratio ranging from $1.2 \leq R \leq 7$.

RESULTS AND DISCUSSION

OASPL Analysis

In impinging jet the presence of obstacle diverts the flow direction. The change in the flow direction results more entrainment and rapid decrease in momentum, which causes more turbulent noise. We can see from Figure 2 (a) to (f), the noise generated in impinging jet is more than free jet. In simplicity we can assume that free jet is a line source of decreasing strength and impinging jet is a combination of two line sources perpendicular to each other in far field. Apart from the turbulent noise there are impinging tones enhances the noise for impinging jet.

Blow up and blow down experiments are carried out for free jet issuing from orifice diameter 8, 10 and 12 mm (Here the result is shown for 10 mm orifice in Figure 2(a)). These free jet tests with different diameters confirms that there is no source of hysteresis at orifice or at initial condition.

Orifice of 10 mm diameter, d and 300 mm diameter plate is used for impinging jet experiments. Nozzle plate spacing, h is varied from d to 10d with intervals of d. It is found that the sound level decreases as nozzle-plate spacing increases more than 2d. Some of the results been compared with the data of Petrie (1974). As the spacing increases the presence of plate in the generation of noise reduces. Figure 2(b) shows there is no hysteresis. Figure 2(c), (d), (e) and (f) indicates the presence of significant hysteresis at NPR = (4-7), (2.75-3.25), (3.9-5.1) and (5-6.1) for h/d = 2, 3, 4 and 5 nozzle plate spacing respectively. This type of hysteresis is observed for pressure and temperature distribution on the impinging plate by Yaga et al. (2006) between the pressure ratio of 3.5 and 4.5, while experimenting on rectangular under expanded impinging jets.

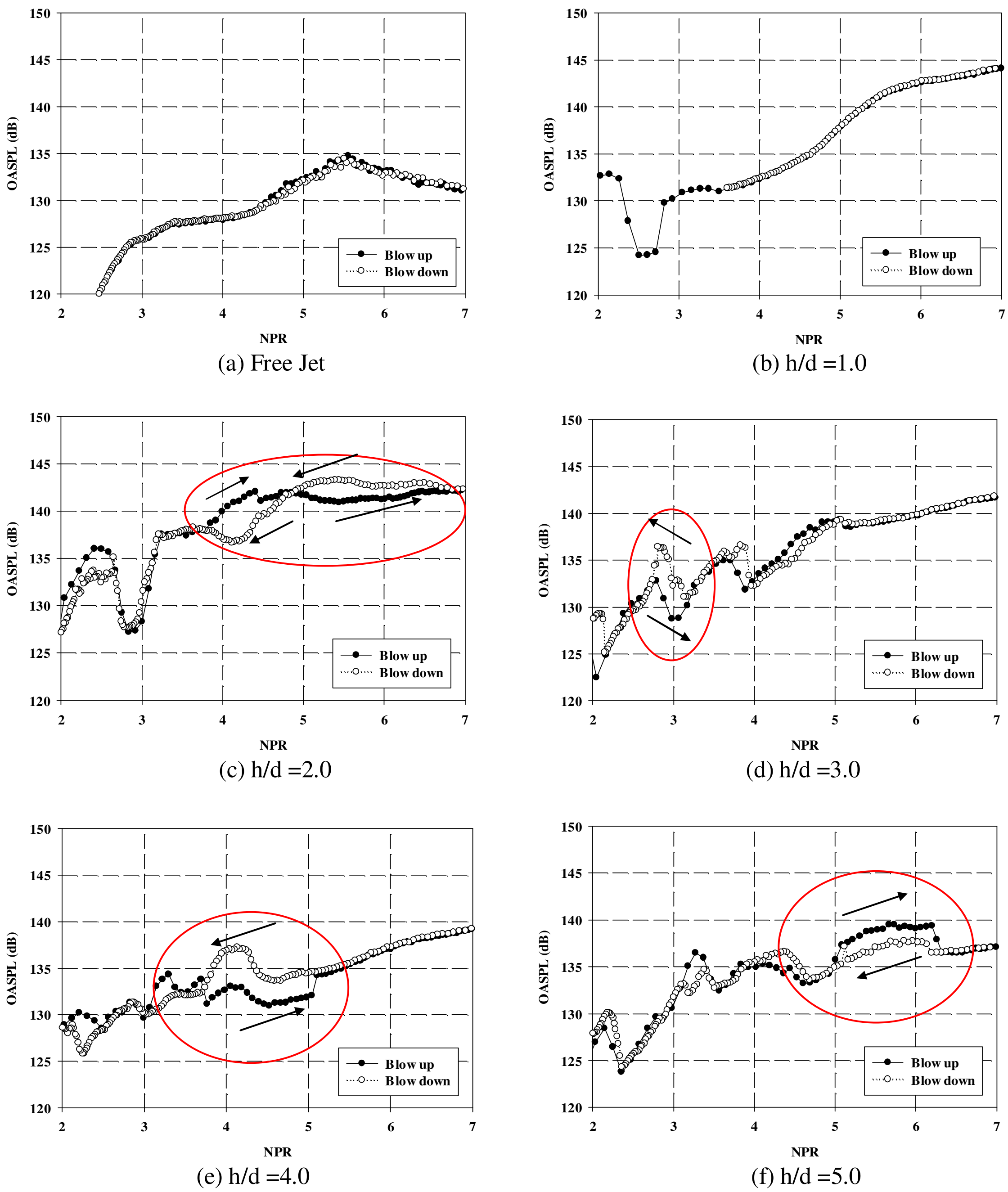


FIGURE 2. Comparison of OASPL radiated during blow up and blow down tests for free and impinging jets with different nozzle-plate spacing

Careful investigation of Figure 2(c) to (f) shows that the location of hysteresis is found, where staging occurs. This gives first impression that hysteresis emerges due to the recirculation zone near the wall present in the impinging jet. Considering this cause the spectral analysis is carried out for the region marked by red oval in Figure 2 (c) to (f). Some of the spectra are shown in Figure (3).

Spectral Investigation

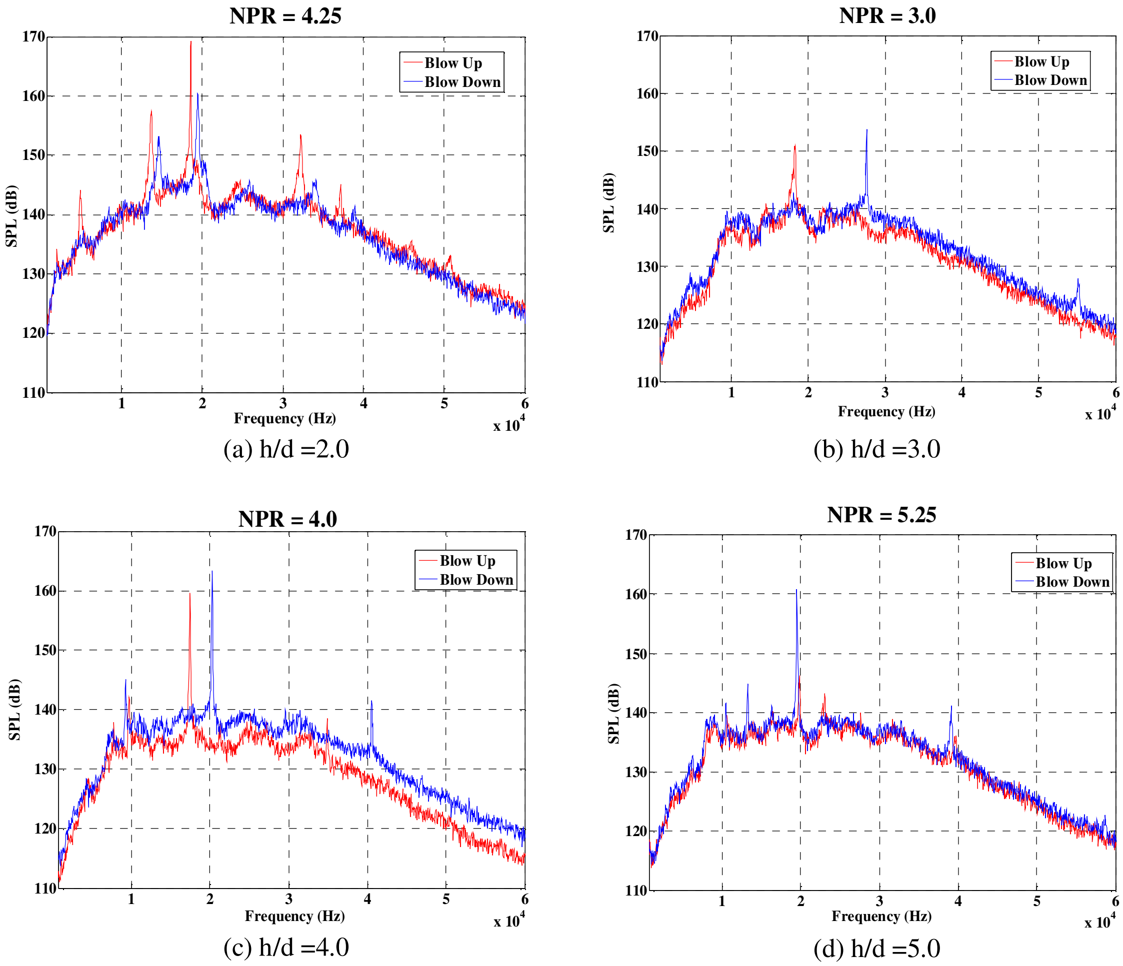


FIGURE 3. Spectral analysis of impinging jet in the region of hysteresis loop

Spectra obtained during blow up and blow down are inspected for same pressure ratio. There is no difference is observed in spectra except in hysteresis loop. Figure 3 shows some of the spectra obtained in hysteresis loop. Figure 3 (a) and (c) indicates that tones are more dominant in blow up than blow down for h/d = 2 at NPR =4.25 and h/d = 4 at NPR = 4.0 respectively. Figure 3 (b) and (d) indicates that tones are more dominant in blow down than blow up for h/d = 3 at NPR =3.0 and h/d = 5 at NPR = 5.25 respectively. The low and high broadband noise components are comparable in all cases except, h/d =4 at NPR =4.0. It is well known that feedback loop is responsible for these discrete tones and it originates from the stagnation zone in case of impinging jets. The change in frequency and strength of these tones in blow up and blow down indicates there may be change in size, shape, strength and number of impinging bubbles.

CONCLUSION

The effect of stagnation pressure under expanded supersonic free and impinging jet with h/d = 1 to 10, accounting hysteresis has been studied. The following observations have been made:

- Free jet and impinging jet with h/d = 1 is free from hysteresis effect.
- Impinging jets with h/d =2, 3, 4 and 5 exhibit hysteresis loops.
- Hysteresis is significant in the region of staging for impinging jet with h/d = 2, 3, 4 and 5.
- The tonal frequencies are affected by hysteresis effects and possibly due to the hysteresis effects in the recirculation zone.

Further tests with flow visualization are needed to identify size and strength of recirculation zone affects the feedback loop and successively amplitude and frequency of tonal noise.

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